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Cognitive Distance Mapping: a Survey-Based Experiment Using GPS and GIS

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ABSTRACT

Two primary objectives of this study were to determine important personal factors in performing cognitive distance mapping, and to understand how human's cognitive distance mapping capabilities were influenced by reference and subjects' locations using Global Positioning System (GPS). Undergraduate and graduate students at the University of Kansas, USA were interviewed and surveyed throughout the campus area giving them a paper-and-pencil test. Study results showed that females had more accurate cognitive mapping capability than males regardless of ethnic background and academic levels. Generally, subjects with longer affiliation with the university, higher ages and academic levels had less variability in their mapping accuracy. Subjects tended to more accurately map the target locations closer to the reference points than those located farther away, and subjects who were closer to a reference point performed their distance mapping better than those farther away. A correlation analysis reported that male subjects used reference-to-target and subject-to-reference distances more sensitively than females to estimate the locations of the targets. This result indicates that males might have used the reference point-based map scale more strenuously than females.

Keywords : cognitive distance, Global Positioning System, paper-and pencil test, mapping accuracy

요 약

본 연구는 인간이 인지거리를 지도화 함에 있어, 성별, 연령, 학년, 수학기간 등의 개인적인 요인과 거리 추정에 사용된 기준점의 상대적인 위치가 거리 추정에 어떤 영

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향을 주는 지를 위치정보 시스템을 이용한 현장 실험을 통해 파악하고자 하였다. 연구 방법으로는, 미국 캔자스대학교에 재학 중인 학부생과 대학원생을 대상으로 캠퍼스 방문을 통한 설문조사를 실시하였다. 자료분석 결과, 여학생 그룹의 거리추정 정확도가 인종이나 학년에 관계없이 남학생 그룹에 비해 높았으며, 전체적으로 학년과 연령이 높아지고 수학기간이 길어짐에 따라 거리 추정 정확도의 분산정도가 감소하는 것으로 나타났다. 인지거리 지도화를 위해 제시된 2개 기준점에 가까이 위치한 건물일수록 거리 추정의 정확도가 높았으며, 설문조사 지점이 기준점에 가까울수록 거리 추정의 오차가 감소하였다. 상관관계 분석 결과, 남학생 그룹의 거리추정 오차값이 여학생 그룹에 비해 건물-기준점 간 거리, 그리고 피실험자-기준점 간 거리와 더 강한 상관관계를 가진 것으로 보아, 남학생이 여학생에 비해 기준점에 근거한 공간적 축척을 더 면밀하게 이용하는 것으로 판단된다.

주요어 : 인지거리, 위치정보시스템, 설문조사, 거리추정 정확도

1. Introduction

Human-beings cognitively represent the surrounding environment in two main ways: maps and experience. A cognitive-map creating process that is based on information from a map is called 'survey mapping,' whereas that from actual behavior or experience in the environment is called 'environmental mapping.' In the process of survey mapping, a cognitive map is created by information gathered from hard copy maps. Especially, if a person has no previous exposure to an area, his or her initial cognitive map develops through survey mapping, and new spatial information is added and updated as the person experiences the environment (Lobben 2004). In the environmental mapping process, repeated visits to a spatial environment update a cognitive map until it arrives to a steady state, where the amount of new information brought to the map with successive visits is minimal (Stern and Portugali 1999). If a person has previous exposure to an area, his or her cognitive map has already established through environmental mapping and the person's cognitive map is updated as he or she looks up a printed map (Lobben 2004).

Cognitive map analyses or cognitive spatial analyses have been conducted primarily by psychologists and cartographers (Downs and Liben 1987; Downs and Liben 1988; Downs and Liben 1991; Klatzky et al. 1998). Three main study categories can be identified regarding people's spatial abilities. First, researchers want to answer the question, 'how do people use or learn a map?' Oftentimes researchers try to understand how well map readers can recall map information after they finish reading it (MacEachren 1992a; MacEachren 1992b; Stern and Portugali 1999; Cornell and Heth 2001). Secondly, researchers have investigated cognitive processes of map reading by which people may mentally re-position a map, psychologically transform information about the relative locations and attributes of spatial phenomena (Lloyd and Steinke 1984; Aretz and Wickens 1992). Finally, researchers have asked, 'how are spatial abilities different among different groups of people?,' or 'what factors are involved in spatial abilities?' Decades ago, researchers investigated if children of school-entering age could learn map skills and have spatial concepts, but the debate has not finished completely (Blaut and Stea 1971; Downs and Liben 1987; Downs et al. 1988: Golledge et al. 1992; Blaut 1997). Numerous studies focused on gender-related differences in spatial abilities (Evans 1980; Harris 1981; Bryant 1982; Gilmartin and Patton 1984; Galea and Kimura 1993; Golledge et al. 1995; Kitchin 1996; Henrie et al. 1997; Montello et al. 1999; Cornell et al. 2003).

Cognitive processes in acquiring spatial knowledge have been tested for decades, but various experimental research produced somewhat different study results. It has been known that human spatial cognition of geographic objects, or geographical positioning capabilities, varies with non-spatial factors, such as gender, age, cultural background, education, and race. Cognitive mapping studies often investigated how spatial knowledge acquisition tasks were performed differently between genders and how young children learned spatial knowledge. However, spatial relations between subjects and their target locations have been rarely incorporated into a cognitive mapping accuracy test. In addition, there has been few studies that investigated the impact of spatial relations between target locations and a given reference point that subjects used to map target locations upon their cognitive mapping processes.

Global positioning system (GPS) and Geographical Information Systems (GIS) techniques allow researchers to conduct numerical analyses of these spatial relations and their impact on human cognitive distance mapping. Accurate geographic locations to be mapped by subjects can be instantly digitized, converted into point feature layers, and analyzed within a GIS environment. To effectively quantify and characterize humans' spatial ability, geospatial techniques need to be incorporated into real world examples. Numerous studies have tested humans' spatial abilities in large scales (small areas), but it is rare that human sense of direction and distance was explicitly quantified and assessed. Without detailed numeric representation, it is very difficult to know if human individuals or groups have different sense of direction and distance. Since GPS and GIS techniques can represent and visualize the accurate positions of humans' cognitive locations, this study is expected to provide an apparent indicator of human's spatial ability. As the human knowledge of space has been a pivotal element in understanding individual's behavior, this type of research will help us solve a fundamental geographical problem, 'how do people select routes to get to their destination?'

University students naturally study the locations of campus buildings and various facilities during their education. Since various types of student groups share the same geographical knowledge of a university campus, a university campus is an ideal place to conduct a cognitive mapping study. Assuming that student subjects have developed their own cognitive maps of their university campus through environmental mapping, it was hypothesized that spatial relations between the subjects and target locations they wanted to map influenced the cognitive representation of their surrounding environment. Focusing on subjects' environmental mapping capabilities, the present study aimed to determine important non-spatial personal factors in performing cognitive distance mapping, and to understand how people's cognitive distance mapping capabilities are influenced by reference and subjects' locations with the aid of GPS and GIS.

2. Methods

1) Study area and participants

This survey was conducted in the Lawrence campus, University of Kansas. Subjects were interviewed at various locations throughout the campus. Subject groups included freshmen, sophomore, junior, senior, and graduate students. These subjects were selected randomly and 39 male and 55 female students participated in the experiment. Six female subjects' answers were incomplete, therefore they were removed from further analyses. Although these subjects were randomly selected, the surveyors tried to collect as much data from minority groups as they could knowing that the campus is dominated by white students. A paper-and-pencil test was given to the subjects, and the subjects were asked to accurately pinpoint the locations of well-known representative buildings or other features on campus with the best of their knowledge. The overall structure and procedure of the test was explained before the subject started the test, and each subject was asked to finish his or her test within ten minutes.

2) Experiment and materials

The purpose of the experimental test was to quantify how accurately the subjects were able to cognitively map out the geographical locations on campus. Sixteen target buildings and features were selected across the campus, and these locations were selected based on the university's official campus map, where these locations were clearly mapped (Figure 1). This campus map is routinely printed in various publications, including university's time table, the university's web site (http://www.ur.ku.edu/maps), the university's phone directory, and local telephone books, as well as many directional signs on campus. Therefore, it was assumed that the subjects were familiar with the locations of the campus buildings and

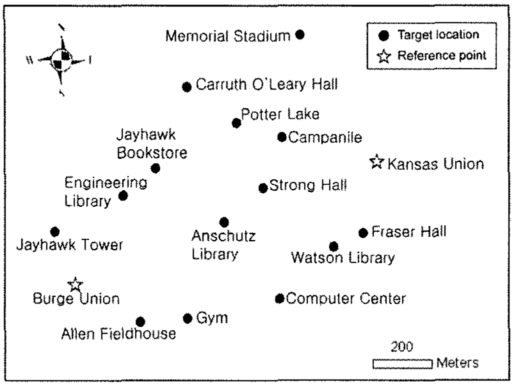

Figure 1. The locations of fourteen target buildings and two reference locations on campus.

Figure 2. An example of a subject's test result.

features. The subjects were asked to map fourteen different campus buildings and features on a letter-sized test paper, where two well-known buildings were provided as subjects' reference locations. The two most popular buildings, Kansas Union and Burge Union, were selected as the reference locations. Along with the other locations, the two reference point locations were recorded by a Garmin handheld GPS receiver with the Universal Transverse Mercator (UTM, zone 15) system and accurately placed on the survey sheet. The subjects were provided a list of the campus locations, and asked to place and label their cognitive locations of the rest fourteen campus locations on the survey sheet, where only the two reference locations were provided (Figure 2).

In addition to the subjects' cognitive locations, the GPS readings of the survey locations were also collected using Garmin handheld GPS receivers. This is because this study intended to investigate if the geographical context of the subjects' physical positions played a role in their cognitive mapping capabilities. For each subject, personal information, such as gender, age, education levels, major, ethnic background, length of affiliation with the university, and confidence level of their mapping capability, was also collected.

3) Distance measurement

After the cognitive locations of the target features were collected from the subjects, their map distances azimuth angles to one of the two reference locations (Burge Union, the left-side reference) were accurately determined using a protractor and a ruler. Using these azimuth angles, map distances, the map scale, and the reference location's UTM coordinates, the northing and easting of each cognitive location were trigonometrically computed. A series of data conversion from map distances to UTM coordinates of the cognitive locations was conducted within Microsoft Excel spreadsheets. With the UTM coordinates of each target location already collected, the offset or location difference between a cognitive location and its counterpart true location was computed for all target features based on the Pythagorean theorem. This location difference was used as an indicator of the subjects' spatial capability.

4) Reference-to-target distance

It is obvious that subjects may use the reference locations to map the target locations. The two reference locations used in the experiment were believed to guide the subjects to map the target locations on the survey sheet. Therefore, the direction and distance of the target locations from the reference points were considered as important factors for the subjects' cognitive mapping. A point-to-point distance measurement was conveniently conducted by extension tools of ESRI's ArcGIS (version 9.1). A point feature layer, containing the two reference and the fourteen target locations, was used as input to compute distances of all possible pairs of the points in the input layer. For this analysis, a spatial analysis extension, called Hawth's Analysis Tools, was downloaded (http://www.spatialecology.com/htools/) and incorporated into ArcGIS. This extension was developed to help spatial ecologists and other scientists perform typical ecological applications, such as movement analysis, resource selection, predator prey interactions and trophic cascades. Point-to-point distance measurement between any pair of point locations within a layer or between two different point layers is one of the useful functions of the extension tool. From the sixteen point locations, a tabular-formatted distance matrix for all pairs of points was created. Once these distances were computed, the SPSS statistical software package (version 14) was used to calculate Pearson's correlation coefficients between subjects' offset distances and reference-to-target distances.

5) Subject-to-reference distance

It was hypothesized that the subjects' geographical context could influence their cognitive mapping ability. In other words, it was expected that subjects' closeness to the reference and target locations would positively influence the mapping ability of the subjects. To analyze the impact of the subjects' relative locations on their mapping accuracy (or offset distance), the distances from each subject' location to the two reference and the fourteen target locations were computed using the Hawth's Analysis Tools extension. For this analysis, two different point feature layers, the target location point layer and the subjects' location layer, were used as input layers. Another distance variable used in the analysis was subject-to-reference distances. It is commonly observed that people use their "You are here" location to estimate the relative locations of other places. Therefore, it was hypothesized that a subject' distance from a reference point would influence the subject's mapping capability. All statistical analyses were conducted with the SPSS software package.

3. Results and Discussion

1) Cognitive mapping accuracy

The accuracy of subjects' distance mapping was defined as the offset distance between their cognitive location and the true location of each target feature. Descriptive statistics provided in Table 1 compares subjects' mapping accuracies based on their gender, age, ethnic background, length of affiliation with the university, academic level, and confidence level. Although statistical significance tests were not available because of the limited number of subjects in each subgroup, experiment results

Table 1. The offset distance between the subjects' cognitive location and the true location of each target location. Grouping criteria included subjects' gender, ethnic background, length of affiliation with the university, academic level, and confidence level (or self-evaluation). Values in parentheses represent the number of subjects in each category.

Personal Factor	male	female	mean
Gender	207 m (39)	195 m (49)	201 m
Ethnic background			
African America	254 m (3)	185 m (1)	237 m
White	208 m (15)	200 m (38)	203 m
Asian	188 m (14)	168 m (9)	182 m
Others	260 m (3)	200 m (1)	245 m
Academic level			
Freshmen	199 m (6)	197 m (15)	197 m
Sophomore	261 m (6)	228 m (10)	240 m
Junior	201 m (6)	198 m (8)	199 m
Senior	219 m (6)	183 m (7)	194 m
Graduate	144 m (15)	164 m (9)	185 m
Self evaluation			
Very good	183 m (7)	155 m (4)	173 m
Good	163 m (12)	159 m (14)	161 m
Fine	245 m (13)	202 m (17)	221 m
Poor	238 m (7)	234 m (11)	236 m
Very poor	n/a	240 m (3)	240 m
Affiliation length			
1 year	184 m (10)	191 m (18)	189 m
1-2 years	262 m (8)	213 m (13)	232 m
2-3 years	182 m (5)	203 m (7)	194 m
3-4 years	210 m (7)	148 m (3)	191 m
4+ years	197 m (9)	187 m (8)	192 m

showed significant differences between these subgroups for comparison purposes.

Gender. Mean offset distances were 207m and 195m for male and female groups, respectively. Female subjects outperformed male subjects in different ethnic groups. To see a gender difference between two largest ethnic groups, American and Asian, African American and White groups were combined together. Figure 3-a shows that males had 7.5% (215m vs. 200m) and 10% (188m vs. 168m) longer offset distances than females in American and Asian groups, respectively. This gender difference consistently existed among different academic-level groups except a graduate student group. Although the degree of difference varied, females outperformed males for all undergraduate student groups (Figure 3-c). These outcomes somewhat deviate from previous test results that dealt with gender-related spatial performance differences. There are numerous studies that showed a statistical gender difference in spatial ability, where males outperformed females. Researchers attributed this gender-related difference to the fact that males performed mental rotation more quickly than females (Goldstein et al. 1990). However, the significance of the statistical tests was not always robust in size depending upon how they defined and measured subjects' "spatial ability."

Ethnic background. Due to the limited number of minority students interviewed, it was difficult to conduct statistical comparison between different ethnic groups. Although the number of subjects was limited in the experiment, noticeable differences between four ethnic groups were observed (Figure 3-b). The Asian student group had the best mapping ability followed by white, African American, and others (Spanish American and African) groups. Especially, the Asian female group showed the best performance with its mean offset distance of 168m, which was 17% shorter compared to the participants' mean, 202m.

Academic level. Since students on higher levels, such as seniors and graduate students, are typically older and have longer affiliation time than the other groups, subjects' offset distance decreased as they advanced to higher education levels. The freshman group, however, did not agree to the overall pattern. On average, these first-year students created more accurate maps than sophomores (Figure 3-c). It is probably because freshmen had to travel significantly more than higher-level students knowing that they typically had their classes in many different buildings across the campus, which might have provided them with recent, extra training in their spatial ability. For example, freshman students mapped libraries (Watson and Anschutz libraries), a bookstore (Jayhawk Bookstore), and Fraser Hall, where various general education courses are taught, significantly more accurately than the other groups, and these locations are where freshman students typically visit frequently regardless their majors.

Length of affiliation. More experienced students on campus tended to have better mapping capability, but the relationship was not very clear. As with age, students with longer affiliation with the university had smaller offset ranges in their cognitive mapping (Figure 3-d). Although the length of affiliation was thought to have the strongest direct relationship with subjects' mapping accuracy, longer exposure to the campus environment did not necessarily mean better mapping performance. Generally, subjects with shorter affiliation time had more variability in their offset distances compared to those who had attended the university longer.

Age. Intuitively, age was expected to have a direct correlation with cognitive mapping accuracy. This is because subjects tend to have longer residency and more exposure to the campus environment with age. However, subjects' age turned out to be weakly correlated with their mapping accuracy (r = -0.21). As

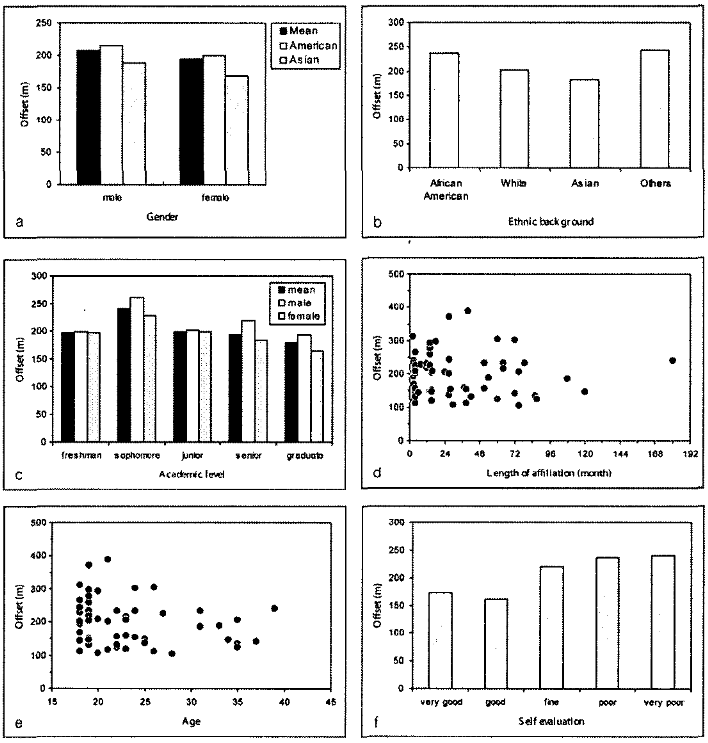

Figure 3. Statistical results of the accuracy of subjects' cognitive distance mapping. Their mapping accuracy was defined as the offset distance between their cognitive location and the true location of each target feature. The statistical difference between subjects' groups was analyzed based on their gender (a), ethnic background (b), academic level (c), length of affiliation with the university (d), age (e), and confidence level (f).

shown in Figure 3-e, a significant number of younger students could map out the target locations as accurately as older students. One noticeable result is that the subjects' mapping ability became more consistent as their age increased. Therefore, the variability of offset distance tapered off with age.

Confidence level. Each student was asked to evaluate his or her own capability of cognitive mapping during the survey. It was scaled with five different classes from 'very good' to 'very poor.' Interestingly, subjects' subjective self-evaluation agreed well with the experiment result. Only the highest-rated group ('very good') was 'overconfident' about their mapping capability, while the other groups matched perfectly the order of the subjects' offset distance measurement. Therefore, offset distance measurements increased as the subjects' confidence level became degraded (Figure 3-f). A recent study by Cornell et al. (2003) reported that there were small to moderate correlations between self-ratings and spatial abilities of adult subjects based on an experiment conducted in a university setting. They also reported that females rated their sense of direction worse than males. A similar result came out of this present study. At the same self-evaluation level, females' offset distances were consistently lower than those of males.

2) Impact of reference-to-target distances

The two reference points were the only means by which the subjects were able to scale their cognitive distance and estimate the locations of the target features. Therefore, their estimation of the direction and distance of the targets locations from the reference points must have been critical part of their mapping. As shown in Figure 1, the reference points were located in an east-west direction. A correlation analysis showed weak to moderate relationships between reference-to-target distances and offset distance measurements. As experiment results were shown in Figure 4, subjects' offset distances became greater as the reference-to-target distances increased. This indicates that the subjects tended to more accurately map the target locations closer to the reference points than those located farther away. It is an intuitively logical and expected result although the strength of correlation between

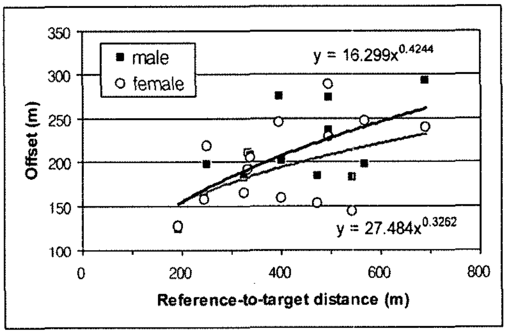

Figure 4. The relationship between subjects' offset distances and the reference-to-target distances. Although it was not a linear relationship, the subjects tended to more accurately map the target locations closer to the reference points than those located farther away.

the two parameters remained to be tested. Figure 5 and 6 show two best and two worst target locations estimated by the subjects, respectively. This pattern occurred for both male and female subjects, but they showed slightly different statistical results. The correlation coefficient between the reference-to-target distance and subjects' offset distances for males (r = 0.63) was higher than that for females (r = 0.46). It seemed that male subjects were more dependent upon or sensitive to the distances from the reference points to the target locations. One noticeable feature was that their offset distances did not increase as the

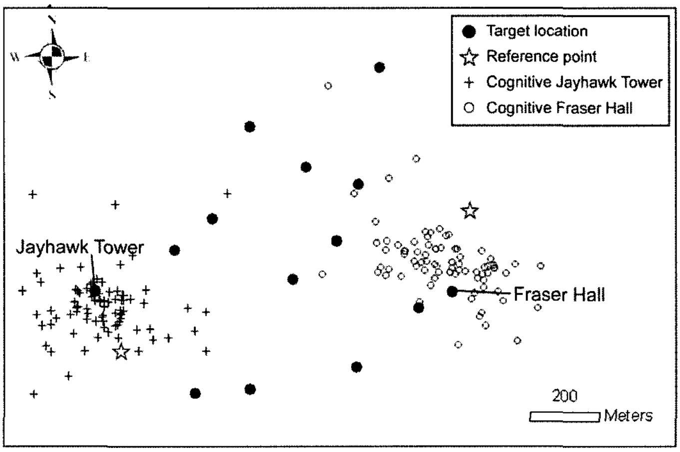

Figure 5. Two target locations that subjects cognitively best mapped: Jayhawk Tower and Fraser Hall. As expected these locations are located most closely to the reference points.

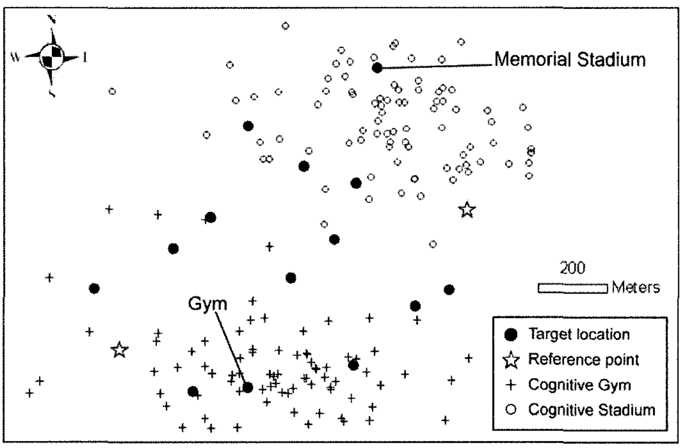

Figure 6. Two target locations that subjects cognitively worst mapped: Gymnasium and Memorial Stadium. These two locations are located near southern and northern boundaries of the campus.

same rate of reference-to-target distance changes. This result may indicate that the relationship between cognitive and actual euclidean distances is not linear. A group of researchers argued that a nonlinear relationship between cognitive and actual distances should suggest the noneuclidean nature of cognitive maps (Canter and Tagg 1975; Baird et al. 1982; Golledge and Hubert 1982; Wiest and Bell 1985; Säisä et al. 1986). However, other investigators argued that the likelihood of noneuclidean judgment could be caused by the degree of familiarity of subjects with the environment they were tested on and the method of measurement (Gärling et al. 1981; Gärling et al. 1982; Gärling et al. 1991). Further investigation on this nonlinearity was not available in this study.

Although these moderate correlations were statistically significant, the analysis based only on the absolute distance between the target and reference locations can be misleading because the two reference points may only control the east-west direction of the subjects' mental space. To evaluate the impact of the directional distances between the reference and target locations on mapping accuracy, two directional departure measures of the target locations from the reference points, horizontal (east-west) departure and vertical (north-south) departure, were computed. These directional departures (DD) were computed by calculating the square root of the sum of the squares (SRSS) of distances of a target location from the two reference points:

$$DD_h = [(\text{easting}_{target} - \text{easting}_{reference1})^2 + (\text{easting}_{target} - \text{easting}_{reference2})^2]^{1/2} \text{ and}$$

$$DD_v = [(\text{northing}_{target} - \text{northing}_{reference1})^2 + (\text{northing}_{target} - \text{northing}_{reference2})^2]^{1/2}$$

DD_h and DD_v are the horizontal and vertical departures, respectively. Easting_{target} and northing_{target} are easting and northing coordinate values of a target location, while $\text{easting}_{reference1}$, $\text{northing}_{reference1}$, $\text{easting}_{reference2}$, and $\text{northing}_{reference2}$ are easting and northing coordinates of the two reference points. These horizontal and vertical departures become greater as target locations get farther away from the mid point between the two reference points in either direction. The experiment result showed that the offset distances decreased as DD_h increased (Figure 7). In

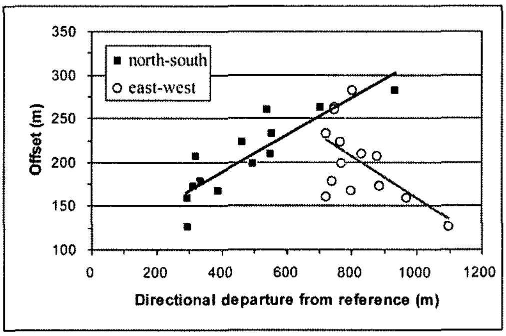

Figure 7. Relationships between target locations' directional departure from reference points and subjects' offset distances. Offset distances decreased as the target locations were closer to any of the two reference points in the east-west direction (r = -0.57). In the north-south direction, however, offset distances increased with DD_v because there was no reference point in that direction (r = 0.87).

other words, as the target locations were closer to the reference points, subjects' offset distances decreased (r = -0.57). The offset distances in the vertical direction changed with DD_v more sensitively. In the north-south direction, offset distances increased with DD_v because there was no reference point in that direction. Therefore, they had a very strong, direct correlation with DD_v (r = 0.87). It is believed that subjects' offset distances were more directly influenced by the vertical departure of the target locations from the reference points than by the horizontal one because there was a directional control (two reference points) in the east-west direction. Due to the lack of reference points in the north-south direction, the directional correlation between offset distances and DD_h was not as high as that in the vertical direction. In this directional test, males had higher sensitivity to DD_h compared to females (Table 2). These two experiment results indicate that males might have used the reference point-based map scale more "strenuously" than females although their overall mapping accuracy was not as good as female subjects'. Lloyd (1989) tested the impact of the location of reference points on distortions in the cognitive maps of subjects, and observed that their judgments were significantly more accurate with centrally located reference points compared to peripherally located ones. This result also indicated that reference-to-target distances were influential for subjects to scale distances cognitively.

3) Impact of subject-to-reference distances

Distances from subjects' locations to individual target locations did not play any role in their cognitive mapping (r = 0.10) as visualized in Figure 8. It is believed that the subjects had already learned the locations of the target features and had not included their closeness to each target location in the cognitive distance mapping process. Rather, they did care more about their relative locations to the reference

Table 2. Pearson's correlation coefficients computed between subjects' offset distances and reference-to-target distances and between subjects' offset distances and directional departure of the target locations from the reference points. Impacts of reference-to-target distances and the target locations' directional departures from the reference points on the subjects' offset distances seemed to be stronger for male subjects than for female subjects.

	Reference-to-target distance	Directional departure	
		DD_h	DD_v
Male	0.63*	-0.66*	0.80*
Female	0.46*	-0.46*	0.86*
Mean	0.55*	-0.57*	0.87*

(* Significant at the 0.01 level.)

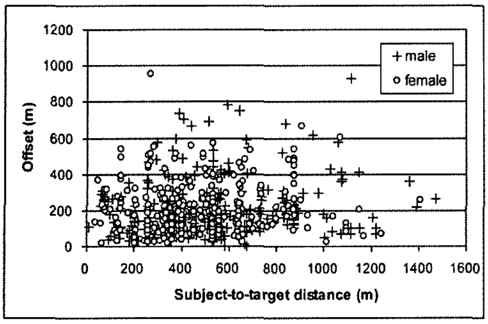

Figure 8. The relationship between distances from subjects' locations to individual target locations and offset distances. There was no correlation between the two (r = 0.10).

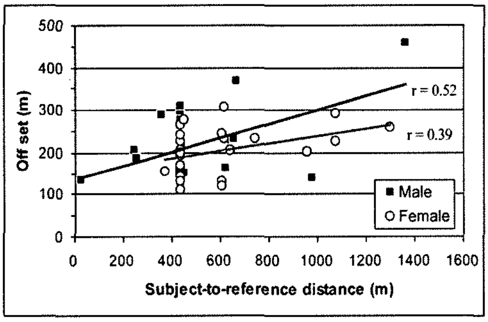

Figure 9. The relationship between distances from subjects' locations to any of the two reference points and offset distances. Subjects who were closer to a reference point performed their distance mapping better than those farther away (r = 0.43). Male and female groups were differently influenced by the subject-to-reference distances.

points. The study result in Figure 9 shows that the subjects who were closer to a reference point performed their distance mapping better than those farther away (r = 0.43). Male and female groups were differently influenced by the subject-to-reference distances. As with reference-to-target distances, subject-to-reference distances were more strongly correlated with male subjects' offset distances (r = 0.52) than female subjects' ones (r = 0.39). To note, these correlations were based on the distance from the western reference point (Burge Union) to the subjects' locations. Interestingly, the distance from the eastern reference point (Kansas Union) to the subjects had no significant correlation with the subjects' offset distances. It seems that the subjects might have used the western (left on the map) reference point as a primary control point.

4. Conclusions

Cognitive scaling and mapping have important implications in understanding how people navigate their surrounding environment and travel destinations. Unlike many previous study results, female subjects estimated distances from reference points to target locations more accurately than male subjects. This result was consistent for different ethnic and academic groups. Despite higher mapping accuracy of the cognitive mapping, females did not use reference points as strenuously as males in their distance judgment. The location of reference points and distances between reference points and target locations contributed significantly to distance scaling of the subjects. Spatial analyses of cognitive distance mapping have many important implications in understanding human behaviors in space. The way that spatial information is stored in human's cognitive space influences their mobility in day-to-day lives and can change the overall cost of the movement. Emergency transportation, mailing/delivery services, tourist guide maps, tracking missing children, and rescue missions in wilderness can benefit from cognitive studies. It is still questionable to know how people use other external features, such as the sun' position, nearby buildings, street networks, and road signs. However, this study demonstrated that a geographical context in terms of reference-to-target and reference-to-subject distances as well as relative locations of reference points played an important role in people's cognitive distance scaling and mapping.

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